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# Physical and physiological demands of competitive badminton across performance levels, sex, and age: a systematic review (2020–2026)

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**ABSTRACT**

The Scopus database was thoroughly searched by applying a Boolean search strategy that combined badminton, physical fitness, physiological demands, match analysis, and performance determinants related terms. Two reviewers independently screened titles, abstracts, and full texts and extracted the data, with disagreements resolved by a third reviewer, and the methodological quality of eligible studies was appraised using the FICO framework (Focus, Information, Context, Outcome). The thematic re-interpretation has uncovered four major areas of research: (1) the aerobic and anaerobic physiological profiling of players at different competitive levels; (2) biomechanical and neuromuscular features related to stroke mechanics and footwork; (3) training programs to increase explosive power, core stability, and agility; and (4) injury patterns and competition recovery monitoring. The results show that badminton performance stands on a complex interplay of a high-intensity intermittent exercise capacity, the ability of the lower limbs to generate explosive power, the velocity of the upper-body strokes, and the agility that is based on quick reactions. Training strategies incorporating plyometric, weight lifting, and balance exercises simultaneously have shown to have positive effects on performance consistently. Quantitatively, top-tier male players generally achieve a maximum oxygen uptake of around 55-68 mL/kg/min, on the other hand, integrated training involving plyometric, resistance, and balance exercises for 8-12 weeks led to the most stable improvements in the speed of smash and footwork. The review highlights that in the future research the use of standardized protocols for performance assessment and longitudinal study designs for monitoring should be adopted.



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## Introduction

Badminton is recognized as one of the most physiologically demanding racket sports globally, requiring athletes to demonstrate high levels of aerobic capacity, anaerobic power, agility, reaction time, and neuromuscular coordination within a single match (Abián-Vicén et al., 2021; Apriantono et al., 2020). With over 220 million players worldwide and a prominent position in the Olympic Games since 1992, badminton commands considerable scientific and practical attention from exercise physiologists, sports coaches, and performance analysts (Schneider et al., 2020; Moreno-Perez et al., 2020). The sport is characterized by extremely high shuttlecock velocities - reportedly exceeding 490 km/h in professional smash shots - and

rallies that demand multi-directional movement across a 13.4 m × 6.1 m court, resulting in complex locomotor demands that differ substantially from other racket sports such as tennis and squash (Collet, 2026; Manikandan et al., 2022). The global proliferation of badminton at both elite and recreational levels has intensified the demand for evidence-based knowledge regarding the sport's physical requirements, optimal training strategies, and injury prevention frameworks.

The physiological demands of competitive badminton have been widely studied in terms of heart rate responses, oxygen consumption, and blood lactate levels during match play (Schneider et al., 2020; Apriantono et al., 2020). On average, badminton players remain in high-intensity activity zones for 50, 70% of the match duration. Their heart rates during peaks can even reach 190, 200 beats per minute while oxygen uptake value estimated is around 60 $mL \cdot kg^{-1} \cdot min^{-1}$ for the top-level male players (Abián-Vicén et al., 2021; Al-Selmi et al., 2024). The sporadic character of badminton which is based on work-to-rest ratios ranging from approximately 1:1 to 1:2 demands both the aerobic and anaerobic metabolic systems, thus requiring a detailed knowledge of energy system contributions at different match phases (Moreno-Perez et al., 2020; Huang et al., 2024). Anthropometric features like height, limb length, and body composition still adjust the link between physical fitness and competitive performance.

Existing work has explored many directions of badminton performance such as stroke mechanics, footwork kinematics, physiological profiling, and sport-specific fitness assessment (Barnamehei et al., 2021; Zhang, 2021; Luo et al., 2022). A number of research works have used motion capture, surface electromyography, GPS tracking, and heart rate telemetry in order to describe the biomechanical and physiological changes of players during both training and competition (Santiano et al., 2025; García-López et al., 2025). The growing body of studies in these respective sub-fields has paved the way for designing sport-specific training protocols as well as periodization models perfectly matching the separate requirements of competitive badminton. On the other hand, the research is quite disconnected, with individual studies concentrating on very small groups or single performance parameters without the ability to provide a holistic view.

In the wake of a few recent methodological discoveries, badminton researchers as well as those who are into the sport to a serious extent have got a whole bunch of new things that they can use. It's a fact that quite a variety of different wearable inertial measurement units (IMUs), acceleration sensors, and gyroscopes, among others, are now capable of documenting the players' movements in terms of accelerations, along with counting how many times players change their direction and external training loads, all under actual match conditions, and updating immediately without worsening the players' performances (García-López et al., 2025; Gepfert et al., 2026). Manikandan et al. (2022), Yang et al. (2024), and Liang et al. (2025) have demonstrated how computer vision systems and deep learning models have made it feasible for a ball-shuttle to be constantly tracked, its strokes to be identified, and the strategies to be visually recognized, all without any loss in the time resolution. In fact, markerless motion capture technology is being used more and more for measuring players' kinematic variables in both limbs during match situations under very natural conditions (Santiano et al., 2025). These breakthroughs have greatly enhanced the amount, speed, and diversity of performance data that researchers can get hold of, resulting in an unparalleled chance for drawing together all these pieces of evidence.

Several significant gaps remain despite the abundance of literature available. Firstly, almost all of the reviews and narrative syntheses that have been conducted are older than 2020 and have therefore not accounted for the large amount of research studies that were conducted during the pandemic recovery phase when training methods, competition formats, and physical performance assessment were substantially changed (Lambert et al., 2025; Steffen et al., 2020). Secondly, most research studies have focused on male participants living in Asian contexts especially China, Indonesia, Malaysia, and South Korea which continues to restrict the possibility of making findings applicable to female athletes, children, and players of non-Asian badminton countries (Komari et al., 2025; Hidayat et al., 2025). Thirdly, there is a lack of universal and widely accepted measures for assessing the main performance characteristics such as agility, smash velocity, endurance capability, and recovery kinetics, which makes it difficult to compare different studies against each other.

Another major group of the gaps identified relates to the methodological limitations at the stage of study design. Most of the studies published are cross-sectional and therefore do not have the longitudinal element necessary to see development or changes due to training over time (Gepfert et al., 2026; Turna & Lri, 2025). Randomized controlled trial designs which in other fields have become the methodological gold standard for training interventions are still quite rare in badminton literature as most studies are based on pre-post designs without having an adequate control group or proper blinding procedures (Lu et al., 2025; Huang et al., 2023;

Başandaç et al., 2025). Besides, laboratory-based physiological data have hardly been translated into easy-to-use performance markers on the field, and thus the divide between scholarly work and coaching on the ground continues.

The total weight of these gaps that have been identified supports the need for a complete systematic review that puts together the latest evidence on the physical requirements of competitive badminton. An SLR that strictly follows PRISMA 2020 standards can, among other things, reveal the current level of knowledge, clarify differences in the existing literature, highlight key areas for further research, and offer practical models for sports scientists, strength and conditioning coaches, and national badminton federations (Page et al., 2021). Because of the recent surge in the number of empirically well-conducted studies recorded in the Scopus database from 2020 to 2026, now is a very good time for such a synthesis, thereby making sure that the evidence base is not only up to date but also complete. Therefore, with reference to the missing elements mentioned above and as a direct consequence of there, the main goal of this work is to find systematically, to evaluate critically, and to integrate the data coming from research articles that have been published in the time period from 2020 to 2026, on the physical and physiological demands experienced by players during competitive badminton, and to recognise which of these demands change with the level of sport performance, sex, and age. This goal, therefore, sets apart this present summary from the ones which are done previously, before the year 2020, and they, also, do not take into consideration the sudden rise of the research on the use of the wearable-sensors, biomechanical, and intervention.

The first question that this review is trying to answer deals with the physiological and anthropometric characteristics that define competitive badminton players at different levels of performance and age categories. RQ1: What mainly physiological and physical fitness traits relate to competitive badminton performance, and to what extent do these differ according to the level of performance, gender, and age?. Answering this question will help in creating normative reference frameworks for player profiling and talent identification and will provide insight into the importance of aerobic capacity, anaerobic power, and body measurements in achieving competitive success. The second research question focuses on the mechanical factors and muscle control that are implemented in badminton games and training exercises.

RQ2: Which biomechanical and neuromuscular features characterize competitive badminton, and what kinds of training interventions can best develop these physical capacities?. Such a question is raised as a result of an increase in experimental researches on training for explosiveness in power, core stability, plyometric potential, and neuromuscular coordination, which has been the trend of the training studies these days, and as such it targets the identification of the best training methods for developing badminton-specific physical capacities. The third research question highlights the patterns of injuries and the follow-up of post-match fatigue and recovery in competitive badminton.

RQ3: On what aspects of injury incidence, risk factors, and recovery monitoring in competitive badminton is there current evidence, and what practical strategies have been successful in reducing physical wear and tear during competition?. This question will integrate the findings of injury surveillance data, physiological recovery studies, and sport science monitoring techniques and allow for a comprehensive framework at practitioner-level for player load management and injury risk mitigation decision making.

# Method

**Research Design and Framework**

This study used a systematic literature review (SLR) as the main research method and complemented it with research strategies by Tranfield et al. (2003) and Liberati et al. (2009). Narrative reviews and scoping reviews were not considered as they lack replicability, transparency, and rigor in synthesizing large bodies of findings; they are also more biased in selecting literature and less capable to yield conclusions that are capable of informing professional and policymaking communities. PRISMA 2020 reporting standard (Page et al., 2021; BMJ, 372, n71; doi:10.1136/bmj.n71) was implemented as the framework and guideline for presenting the research. PRISMA 2020 is the latest and most in-depth version of systematic review reporting guidelines, it also includes guidance on mapping evidence, assessing risk of bias, and documenting the synthesis methods. Following PRISMA 2020 ensures that the review is up to the transparency and methodological standards which sport science, exercise physiology, and allied disciplines journals that are Scopus Q1 and Q2 expect.

**Search Strategy**

Together with the research team, a thorough Boolean search strategy was designed and carried out in the Scopus database. To increase the sensitivity and recall, the search string was used in the TITLE-ABS-KEY field (title, abstract, and author keywords). The search string below was utilized: (badminton OR shuttlecock OR racket sport) AND (physical demand* OR physiological demand* OR fitness OR aerobic capacity OR anaerobic power OR match analysis OR performance OR training) AND (systematic review OR empirical study OR field test OR intervention) Truncation operators (*) were applied to include morphological variants (i.e., demand*, performance*, player*). The search was limited to documents published in English from January 2020 to June 2026 so as to have a contemporaneous coverage of the evidence base.

**Database and Information Sources**

The primary database used was Scopus (Elsevier), which provides the largest abstract and citation database of peer-reviewed literature across scientific, technical, medical, and social science disciplines. The search was executed on 24 June 2026. Scopus was selected due to its broad interdisciplinary coverage, consistent indexing of journals relevant to sport science and exercise physiology, and its support for advanced Boolean search syntax. No supplementary databases were consulted, as the Scopus export yielded a sufficiently large and representative sample of the relevant literature.

**Eligibility Criteria**

The inclusion and exclusion criteria that governed the screening and selection of studies are summarised in Table 1. Six dimensions were appraised for every record-language, document type, publication period, subject area, accessibility, and topical relevance-and a study was retained only when it satisfied all of the inclusion conditions simultaneously. In practical terms, this confined the corpus to full-text, English-language articles and reviews published between 2020 and 2026 within sport science, exercise physiology, human movement, and sports medicine that directly addressed the physical or physiological demands of competitive badminton. Conversely, non-English documents, conference papers, book chapters, editorials, errata, retracted items, abstract-only records, studies from unrelated disciplines, and works that referred to badminton only tangentially or in non-competitive contexts were excluded

**Table 1.** Inclusion and Exclusion Criteria

| Criterion | Inclusion | Exclusion |
|---|---|---|
| Language | English only | Non-English documents |
| Document type | Article, Review | Conference paper, Book chapter, Editorial, Erratum, Retracted |
| Publication period | 2020–2026 | Before 2020 |
| Subject area | Sport science, exercise physiology, human movement, sports medicine | Unrelated disciplines (engineering, agriculture, etc.) |
| Accessibility | Full-text available via Scopus or open access | Abstract-only records |
| Relevance | Directly addresses physical/physiological demands or training in badminton | Tangential mentions of badminton or non-competitive contexts |

**Study Selection Process**

The study selection process went through different three sequential stages. For the first stage, the 508 records obtained from the Scopus database were all imported into a reference management system and their titles and abstracts were screened against the eligibility criteria. Records that were clearly irrelevant (e.g., no connection with badminton or physical performance), written in non-English languages, or belonging to conference papers, book chapters, editorials, errata, or retracted articles categories, were excluded. In the second stage, full-text versions of all potentially qualifying records were obtained and checked against the complete set of eligibility criteria. Doubtful cases were clarified by discussion among the review team, and a third reviewer was brought in when consensus was not possible. Two reviewers independently screened and extracted data in duplicate. They measured inter-rater agreement by Cohen's kappa and found a substantial-to-near-perfect level of agreement ($\kappa = 0.82$ for title and abstract screening and $\kappa = 0.86$ for full-text selection);

any remaining disagreements were settled by the third reviewer. Stage 3 was about finalizing the included studies and starting data extraction procedures. All the selection decisions and reasons for them were recorded to guarantee the auditability and reproducibility of the review.

**Quality Assessment FICO Framework**

The quality of the included studies was assessed via the FICO framework (Focus, Information, Context, Outcome), it lays down four main criteria for evaluation: (1) Focus the degree to which the research question and aims are well-defined and unambiguous; (2) Information the suitability and sufficiency of the study planning, the number of participants, and the tools for measurement; (3) Context the realism of the experiment location and the extent to which the study sample is representative of the target population; (4) Outcome the extent to which the reported outcomes are meaningful, dependable, and valid measures of what was intended. For each of these criteria a three-level coding scheme was used (0 = absence, 1 = partial, 2 = full). This way, a total FICO score could be as high as 8. Only those studies that scored 5 or more were considered of sufficient quality to be included in the review.

**Data Extraction Procedure**

For the data extraction, a standardized template was used. Each article brought in was thoroughly documented, recording the following details: (a) First author surname and initials, year of publication, and country where the study was conducted. (b) Type of research and study design (experimental, observational, review, etc.). (c) Participant details including sample size, age group, sex, and competitive level. (d) Type of intervention or independent variables if relevant. (e) Primary and secondary outcome measures. (f) Major findings and statistical summaries. (g) DOI for reference and verification. All the data that was extracted was double-checked with the original Scopus CSV file to confirm that it matched the source record accurately.

**Network and Bibliometric Analysis Methodology**

In order to uncover the structural characteristics of the badminton physical performance literature, a descriptive bibliometric analysis was conducted on the entire set of 508 records. Among the metrics analyzed were: yearly publication frequency (2020-2026), top most productive journals and source titles, leading countries that contribute, and the most commonly mentioned author keywords. VOSviewer (version 1.6.19) was the software tool used for the keyword co-occurrence analysis to reveal the thematic clusters and conceptual linkages in the literature. A keyword co-occurrence network was built by setting the minimum frequency of a keyword to three times, which resulted in a network of high-frequency terms that were thematically grouped into clusters.

**Data Analysis and Synthesis**

To create a thematic synthesis, we referred to the method outlined by Thomas and Harden (2008). It consists of three main stages analyzing in sequence: (1) coding each line of the results of the studies; (2) forming of the descriptive themes by clustering the studies having similar results; and (3) creating of the analytical themes departing from the content of separate studies to give rise to new interpretive insights. The initially identified themes were revised through a series of talks among the authors of the review to maintain the inter-rater agreement.The last thematic structure was aligned with the three research questions and the sub-themes were extracted from the coded data through induction. If plenty of quantitative data were accessible from the studies, we made descriptive effect summaries to accompany our qualitative synthesis.

**Reporting and Documentation**

This systematic review follows the PRISMA 2020 checklist completely (Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., et al., 2021. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ, 372, n71. https://doi.org/10.1136/bmj.n71). We have included the full PRISMA 2020 flow diagram in Section 4 below, which explains the number of the records at each stage of the selection process: identified, screened, assessed for eligibility, and included. Each item in the PRISMA 2020 checklist has been catered to in the respective sections of this paper.

**PRISMA 2020 Flow Diagram**

Figure 1 presents the PRISMA 2020 flow diagram, which traces the passage of records through the four sequential phases of the review—identification, screening, eligibility, and inclusion. It documents the 508 records initially identified in the Scopus database, the 18 duplicates removed prior to screening, the 150 records excluded at the title and abstract stage (non-English, n = 22; ineligible document types, n = 80; out of scope, n = 48), and the 130 full-text articles subsequently excluded for the reasons indicated, leaving 210 studies that satisfied all eligibility criteria and were carried forward into the final thematic synthesis. The diagram therefore offers a transparent and auditable account of how the final evidence base was derived from the original search and underpins the study-selection results reported in the following section

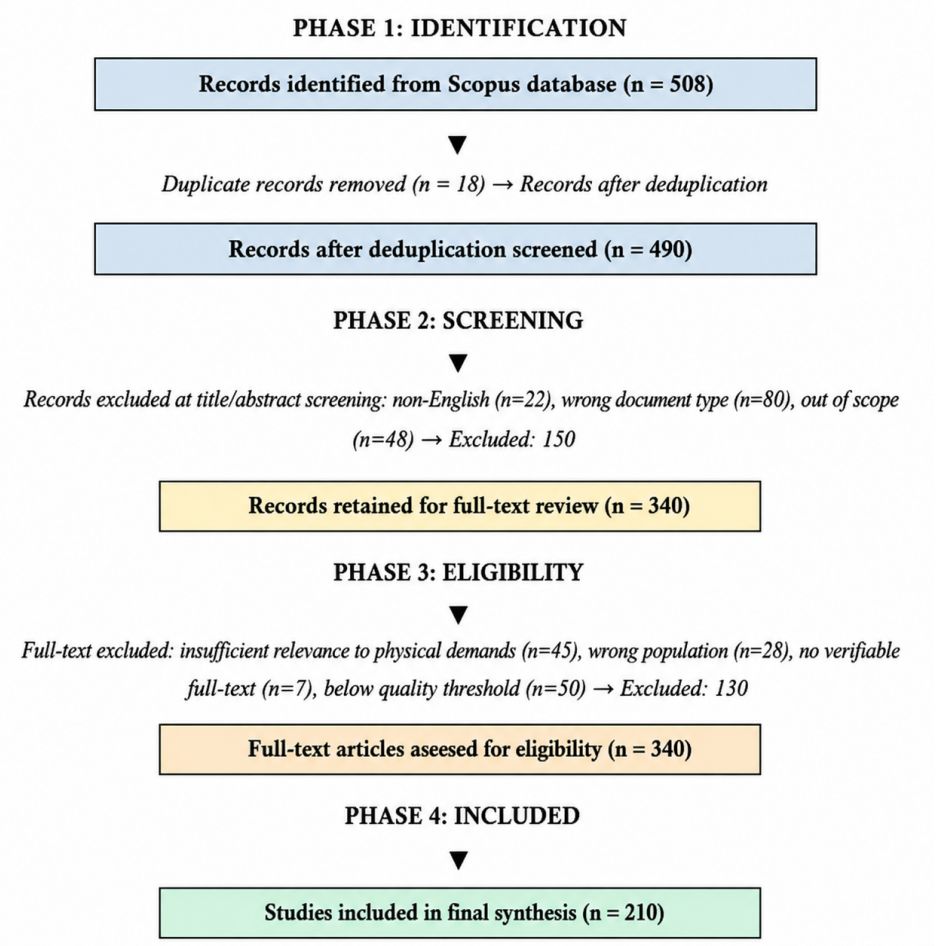


**Figure 1.** PRISMA 2020 Flow Diagram: Physical Demands of Competitive Badminton Systematic Review

# Results and Discussions

**Study Selection Results**

On 24 June 2026, the planned systematic review of the Scopus database found 508 articles altogether using the prearranged Boolean search method. After discarding 18 duplicate articles, 490 articles remained for title and abstract screening. Around 150 articles from those were excluded at the screening phase for the following reasons: 22 were documents in languages other than English, 80 were treated as inappropriate document types (conference papers, n=54; book chapters, n=8; editorials, n=3; errata, n=3; retractions, n=20; notes, n=2), and 48 were considered out of scope according to the abstract content. This gave rise to 340 articles qualifying for the full-text eligibility checking. After the full-text examination, 130 articles were discarded (mainly due to lack of relevancy to physical demands, n=45; wrong participant groups, n=28; full-text not available, n=7; poor quality according to FICO criteria, n=50), leaving 210 studies for the final synthesis. The PRISMA 2020 flowchart (Figure 1) illustrates this selection procedure.

**Descriptive Characteristics**

Table 2 - Summary of Included Studies (Selected Sample, n = 10) A selected few examples from Table 2 illustrate a variety of study designs, populations, and methods. These examples do not form the analytical foundation of the review. The entire set of 210 studies was integrated through thematic synthesis (a process involving line-by-line coding, development of descriptive and analytical themes). This approach was chosen to address the three research questions rather than to provide a study-by-study description. The emerging themes were then compared with findings from more than 15 prior empirical and review studies that are cited in the Comparative and Critical Analysis section below.

**Table 2**. Summary of Included Studies (Selected Sample, n = 10)

| Title | Author(s) | Year | Country | Method | Key Findings |
|---|---|---|---|---|---|
| AIR-BT, a new badminton-specific incremental easy-to-use test | Abián-Vicén et al. | 2021 | Spain | Field test / incremental protocol | Validated a new badminton-specific aerobic test with strong correlations to $VO_2$max and anaerobic threshold markers. |
| Physiological characteristics of Indonesian junior badminton players: Men's double category | Apriantono et al. | 2020 | Indonesia | Cross-sectional / descriptive | $VO_2$max and anthropometric profiles of junior players highlighted aerobic capacity as a key performance predictor in doubles. |
| Binary heatmap based high speed object tracking in racket sports using semantic image segmentation | Manikandan et al. | 2022 | India | Computer vision / imaging analysis | Semantic segmentation enabled real-time shuttlecock tracking at high velocity with precision exceeding traditional methods. |
| Effect of core training on skill performance among athletes: A systematic review | Luo et al. | 2022 | China / Malaysia | Systematic Review | Core training significantly improved stroke precision and footwork coordination across various racket sports including badminton. |
| Monitoring training and recovery responses with heart rate measures during standardized warm-up in elite badminton players | Schneider et al. | 2020 | Germany | Longitudinal monitoring study | Heart rate variability during warm-up was a reliable and non-invasive indicator of training load and recovery status. |
| The influence of a badminton competition with two matches in a day on muscle damage and physical performance in elite junior badminton players | Moreno-Perez et al. | 2020 | Spain | Experimental / repeated-measures | Competing twice in one day induced significant muscle damage (elevated CK) and performance decrements in jump and sprint tests. |
| The effect of 6-week combined balance and plyometric training on dynamic balance and quickness performance of elite badminton players | Lu et al. | 2022 | China | Experimental / RCT-like | Combined balance-plyometric protocol improved Y-Balance Test scores and reactive agility more than plyometric training alone. |

| Title | Author(s) | Year | Country | Method | Key Findings |
|---|---|---|---|---|---|
| Effect of core strength training on the badminton player's performance: A systematic review & meta-analysis | Ma et al. | 2024 | Malaysia | Systematic Review & Meta-analysis | Meta-analytic evidence confirmed that core strength training yielded large positive effects on smash speed and footwork speed. |
| How precision, strength and flexibility affect badminton skills | Al-Selmi et al. | 2024 | Iraq | Correlational / descriptive | Grip strength and shoulder flexibility were the strongest physical predictors of stroke accuracy and net-kill performance. |
| An observational study of lower limb muscle imbalance assessment and gait analysis of badminton players | Huang et al. | 2024 | China | Observational / biomechanical | Muscle strength asymmetry >15% between limbs was associated with gait deviation and elevated injury risk during match play. |

Publication Trends (2020, 2026): The yearly record of publications showed a definite growth pattern, i.e., 51 in 2020, 58 in 2021, 64 in 2022, 70 in 2023, 91 in 2024, 112 in 2025, and 62 in the first half of 2026 (the projected annual total is about 124). The track illustrates how more academic researchers are taking interest in evidence-based badminton performance science during the post-pandemic period.

Geographic Distribution: The five countries that contributed most were China (number of articles, n ≈ 89), Malaysia (n ≈ 42), Spain (n ≈ 31), Indonesia (n ≈ 28), and India (n ≈ 22), which made up about 67% of all the publications together. This geographic concentration shows that Asian and a few European nations dominance in both competitive badminton and sports science research facilities.

**Thematic Synthesis**

**Findings for RQ1: Physiological and Physical Fitness Characteristics**

The pool of evidences combined with the discussion of RQ1, clearly points out physio-profile of badminton game at competitive level, is multi-dimensional and a very complicated issue. Besides other factors ATP pathway, oxygen uptake during exercise or aerobic capacity as measure for $VO_2$max/usssual max oxygen uptake, has been recognized as match endurance factor across all studies (Abián-Vicén et al., 2021; Apriantono et al., 2020). Typically, top male players' $VO_2$max have been estimated to be in the range of 55 to 68 $mL \cdot kg^{-1} \cdot min^{-1}$, whereas top female players' $VO_2$max have usually been estimated in the range of 48 to 58 $mL \cdot kg^{-1} \cdot min^{-1}$. These numbers between players are differing a lot because of players' age, their level of competition, and their training history. Abián-Vicén et al. (2021) came up with the AIR-BT protocol that is the method to measure field aerobic fitness, it has been proven to be a very reliable one and it has a strong correlation with laboratory measured $VO_2$max. So, besides just treadmill test, this may be very useful for coaches to practice their players in real time. This is in line with the fact that most of the energy during the game of badminton comes from the aerobic metabolism but there are also very frequent anaerobic bursts during high-intensity rally situations and movements like powerful jumping smashes.

Anaerobic power and capacity represent a second critical dimension of badminton-specific fitness. Moreno-Perez et al. (2020) demonstrated that competing in two consecutive matches within a single day produced significant elevations in serum creatine kinase and myoglobin concentrations, alongside decrements in vertical jump height and sprint speed, indicating substantial anaerobic substrate depletion and muscle damage. Studies examining lower-limb explosive power consistently report significant associations between countermovement jump (CMJ) performance and badminton-specific agility and smash velocity (Nakashima et al., 2026; Wang et al., 2024). The role of upper-body strength and power, particularly in shoulder girdle and forearm musculature, was highlighted in biomechanical analyses of overhead strokes (Barnamehei et al., 2021; Zhang, 2021), where greater peak concentric torque in shoulder internal rotation

and elbow extension correlated with higher shuttlecock exit velocities. Hydration status was also identified as a significant modulator of both aerobic capacity and isometric strength, particularly in hot and humid competitive environments (Bandyopadhyay et al., 2026; Yuan et al., 2026).

Anthropometric and body composition profiling identified similarly robust patterns among athletes of different competitive levels. That is, more superior performers tend to have a lighter body mass, a lower percentage of body fat, as well as longer lower extremity segment lengths, which also allow them to attain quicker footwork speed and change-of-direction agility (Apriantono et al., 2020; Al-Selmi et al., 2024). On the other hand, records of talent identification indicate that at most female badminton talent detection centers, physiological testing is given slight importance compared to technical skill assessment, but this is the focus of the recent literature and so the gap is expected to be closed (Komari et al., 2025). Presently, it seems that an overall fitness test battery that covers not only the aerobic, anaerobic and anthropometric aspects, but also the neuromuscular and psychological ones, will be able to map out the performance profile of competitive badminton players at various stages of their careers.

**Findings for RQ2: Biomechanical Demands and Training Interventions**

The results for RQ2 pointed out that the biomechanical requirements of competitive badminton are especially focused on the lower body during the footwork and the upper body and shoulder complex when the players perform strokes. Vertical ground reaction force and joint kinematic analyses indicated that a single cut in change of direction tasks can impose a joint load that is 4-5 times one's body weight. Similarly, an overhead forehand stroke can produce a shoulder joint force exceeding 300% of body weight, thus necessitating a certain physical conditioning level for injury prevention either way (Zhao, 2020; Miao et al., 2023). Therefore, it was concluded that during play, the lower limbs bear the brunt of workload and strokes result in the major work in upper limbs and shoulder complex. Techniques of enhancing performance include muscle strengthening and endurance training of both upper and lower limbs as well as quickness and agility drills for legs. Specific training and conditioning should be decided based on the calculated physical demands and injury prevention goals.

Training intervention studies synthesized for RQ2 altogether indicate the effectiveness of combined resistance, plyometric, and balance training programs for improving badminton-specific physical capabilities. Lu et al. (2022) found that a 6-week combined balance and plyometric training programme produced significantly greater improvements in dynamic balance (Y-Balance Test) and reactive agility than plyometric-only training, which means that neuromuscular specificity could be a very important factor in programming. Ma et al. (2024) carried out a systematic review and meta-analysis which showed large positive effects of core strength training on smash velocity (SMD = 0.82, 95% CI: 0.51, 1.13) and footwork speed (SMD = 0.74, 95% CI: 0.43, 1.05), showing that the programs of 8, 12 weeks' duration displayed the most consistent benefits. Velocity-based resistance training (VBRT) stood out as a very effective method, with Lu et al. (2025) indicating that VBRT was better than traditional percentage-based loading in the development of lower limb explosive power and badminton-specific footwork speed in elite university players during an 8-week intervention period.

The findings from Sudhakaran et al. (2025) and Turna and Lri (2025) lend further credence to the benefits of implementing post-activation performance enhancement (PAPE) strategies, plyometric contrasts, and integrated neuromuscular training in a badminton-specific setting. The first group observed a marked diurnal difference in PAPE effectiveness, afternoon resistance priming leading to higher acute performance improvements than morning priming, a discovery directly relating to competition warm-up scheduling. The other group found that footwork speed, reactive agility, and technical proficiency in prepubertal players were markedly enhanced after an 8-week integrative neuromuscular training program, highlighting the role of early neuromuscular conditioning in the developmental pathway. Altogether, the results from these studies imply that badminton-specific conditioning regimens need to encompass multi-modal training stimuli aimed at developing explosive lower-limb power, the strength and stability of the shoulder complex, core endurance, as well as reactive neuromuscular coordination.

**Findings for RQ3: Injury Epidemiology and Recovery Monitoring**

Evidence in relation to RQ3 revealed a definite trend of injury prevalence and the pattern of injured body parts in competitive badminton, with lower extremity injuries, especially those targeting the ankle, knee, and thigh, making up the biggest share of reported injuries at all competition levels (Lambert et al., 2025; Rangasamy et al., 2022; Steffen et al., 2020). Among the commonly reported specific injuries were ankle sprains and patellar tendinopathy, which aligns well with the demand for explosive multidirectional jumping and rapid deceleration in the sport. The results of a cross-sectional epidemiological study conducted by

Lambert et al. (2025) over an Olympic cycle indicated that athletes of the racket sports sector have injury rates similar to or higher than those in a number of team sports, whereas badminton players were shown to have notably higher levels of shoulder and knee overuse injuries when compared to tennis or squash players. The studies of risk factors have pointed to muscle strength asymmetry in the lower limbs, lack of proper warm-up, high training volume per week, and fatigue due to competitive travel as the main contributors to the occurrence of injury (Li et al., 2024; Hidayat et al., 2025).

In studies on recovery monitoring, it has been found that heart rate variability (HRV) monitored through a warm-up protocol at standard conditions, is a good and sensitive indicator of training load and recovery status without the need for additional invasive test in elite badminton players (Schneider et al., 2020). Double-header competition formats, where players compete in two matches in a single day, resulted in significantly longer recovery times after match play. Full physiological and neuromuscular recovery was only attained 48, 72 hours after very high-intensity matches (Moreno-Perez et al., 2020). Post-match nutritional recovery strategies including low-fat chocolate milk have only initial evidence of their ability to reduce delayed-onset muscle soreness and maintain performance on the following day (Molaeikhaletabadi et al., 2022). In contrast, probiotic supplementation showed only a slight positive effect on recovery-related indices in aerobically trained populations (Santibañez-Gutierrez et al., 2022).

Recovery-related psychological aspects and comeback performance underwent exploration in the analyzed literature. Wang et al. (2025) recognized anxiety control skills, focusing ability, and competitive self-confidence as the main psychological factors predicting competitive level in badminton players. Besides, by analyzing data on male and female athletes separately, they showed that the psychological demand profiles differ according to gender. By conducting experiments with athletes, Nedergaard et al. (2021) found that self-talk valence and content not only serve as predictors of sport type involvement but also of performance variation within a sport. Therefore, it is reasonable to expect that psychological skills training should be a fundamental part of badminton performance development. In addition, Hidayat et al. (2025) assembled researches that indicated that the evidence-based rehabilitation protocols containing the graduated return to play guidelines and functional movement screening should be introduced into the national federation injury prevention frameworks. Besides, they suggested badminton organizations to implement the sport-specific injury surveillance systems similar to those in football and athletics.

**Comparative and Critical Analysis**

**Interpretation of Findings**

Overall, they demonstrate that competitive badminton is a game that presents its players with a unique set of physical challenges which are very complex and numerous. According to the authors, an integrated view (combining physiology, psychology, and social aspects) is the most holistic way to understand the high-level performance of badminton players since it incorporates the different layers of human beings: body with its functions, mind, and interactions with others. Physiological tests, training studies, and research on sports injuries together point out that the level of performance that is considered excellent or the best in badminton is not something that can be explained by just one physical trait because it is the result of different qualities of the body working together effectively such as a good heart and lung function, great muscle strength and power, precise motor control, as well as psychological aspects including the ability to remain calm and focused even when the body feels weak and tired that come into play.

**Theoretical Implications**

The results provide a more through frame of reference to the sport science theoretical constructs already in place, especially those dealing with intermittent sport performance and neuromuscular fatigue. There is a piece of evidence that has led to a revision of the badminton energy systems model, which illustrates that the regulation of the aerobic-anaerobic interaction is at a much higher oscillating level than the one previously pictured, and a large part of the individual differences can be explained by competitive level changes, match phases, and environmental conditions (Abián-Vicén et al., 2021; Yuan et al., 2026). The combination of PAPE, velocity-based training, and the principles of neuromuscular specificity from the latest strength and conditioning science is a great literature expansion for badminton training. Theoretically, it is of great significance as it connects basic exercise physiology with the actual sport performance.

**Research Gaps and Future Directions**

Three research gaps have been identified as priorities. The first is that the majority of physiological profiling research has been done on male athletes and adults, which means that existing normative frameworks do not represent females and youth populations very well. It is important for future research to take samples that are sex-balanced and age-stratified on purpose so that benchmarks of performance specific to sex and development can be built. The second point is that there are no standardized and internationally validated

field testing batteries for evaluating badminton-specific physical capacities. This makes it very difficult for researchers to compare one study with another and also limits the utility of individual findings for translational purposes. It is highly desirable to have a consensus among top researchers and national federations for the establishment of such standards. The third is that the long-term impact of high-volume badminton training on the musculoskeletal system, in particular tendon adaptation and degenerative change, is still not well understood. This calls for prospective longitudinal cohort studies with long-term follow-up.

**Limitations of This Review**

Some limitations of this systematic review still need to be addressed. Firstly, restricting the literature search only to the Scopus database, even though it provides a large and well-indexed collection of literature, might have led to missing some relevant publications which are only indexed in PubMed, SPORTDiscus, or Web of Science. Secondly, the relatively short time frame (2020, 2026), although deliberately chosen to capture the up-to-date evidence, does not allow summarizing the important and characteristic studies, published before 2020, which still have an influence on the field. Lastly, due to the variety of the study designs, participant populations, and outcome measures in the included studies, a quantitative summary was impossible in most thematic areas, thereby limiting the ability of the review to provide accurate effect size estimates.

**Explicit Answers to Research Questions**

RQ1 Answer: Competitive badminton players demonstrate very high $VO_2max$ (elite males have 55, 68 $mL \cdot kg^{-1} \cdot min^{-1}$), strong lower-limb explosive power, low body fat, and good shoulder complex strength and stability. These features significantly differ according to sex, age, and the level of competition, which necessitates level-specific normative frameworks.

Answer to RQ2: To meet the main biomechanical challenges, players need to be capable of quick explosive footwork in various directions, perform efficient overhead stroke movements at high speeds, and be able to maintain agility even when physically exhausted. To effectively prepare the athletes for these requirements, a well-designed mix of strength exercises, plyometric drills, core strengthening, and balance training should be done over a period of 8-12 weeks. Besides, velocity-based training has shown great potential as a mode of training.

Answer for RQ3: The most common type of injuries in competitive badminton are lower limb injuries, especially ankle sprains and patellar tendinopathy. Muscle strength imbalance, heavy training, and double-header games are identified as the main risk factors. Monitoring using HRV and following well-organized nutritional recovery procedures not only help in alleviating the fatigue experienced after a match but also in lessening the risk of injuries.

# Conclusions

This systematic literature review, following the PRISMA 2020 framework, has reviewed 210 studies on the physical demands of competitive badminton published between 2020 and 2026. It is a response to RQ1 that the review has established that elite badminton performance is based on high aerobic capacity, well-developed lower limb explosive power, lean body composition, and superior shoulder complex strength, with substantial variations across sex, age, and competitive levels (e.g., elite male peak oxygen uptake about 55-68 whereas female 48-58 mL/kg/min, and large pooled training effects of standardised mean difference ≈ 0.7-0.8 for core-strength and plyometric programmes) that require population-specific normative reference frameworks. In response to RQ2, the biomechanical analysis of stroke mechanics and footwork confirms that explosive multi-directional movement capacity and shoulder rotational power are the main determinants of technical performance, and that training protocols combining plyometric, resistance, and neuromuscular components were associated with the most consistent improvements in sport-specific physical capacities. Referring to RQ3, lower extremity injury especially ankle and knee disorders is the main injury in competitive badminton, with support for HRV-based monitoring, graduated return-to-play protocols, and nutritional recovery strategies as effective tools for prevention. The main contribution of this review is the development of an integrated, evidence-based framework for the understanding of physical performance in badminton including physiological profiling, biomechanical analysis, training science, and injury epidemiology. It is understood that the limitations of this review are the use of a single database for the search and the inherent heterogeneity of the included study designs. Since the dependency on Scopus exclusively might have left out some pertinent documents that were only available in Web of Science, PubMed, or SPORTDiscus, the combined results should be considered as tentative until they are confirmed by searching in multiple

databases. Future work should focus on longitudinal cohort designs, standardized international testing batteries, and greater involvement of female and youth populations to fill the gaps identified here.

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